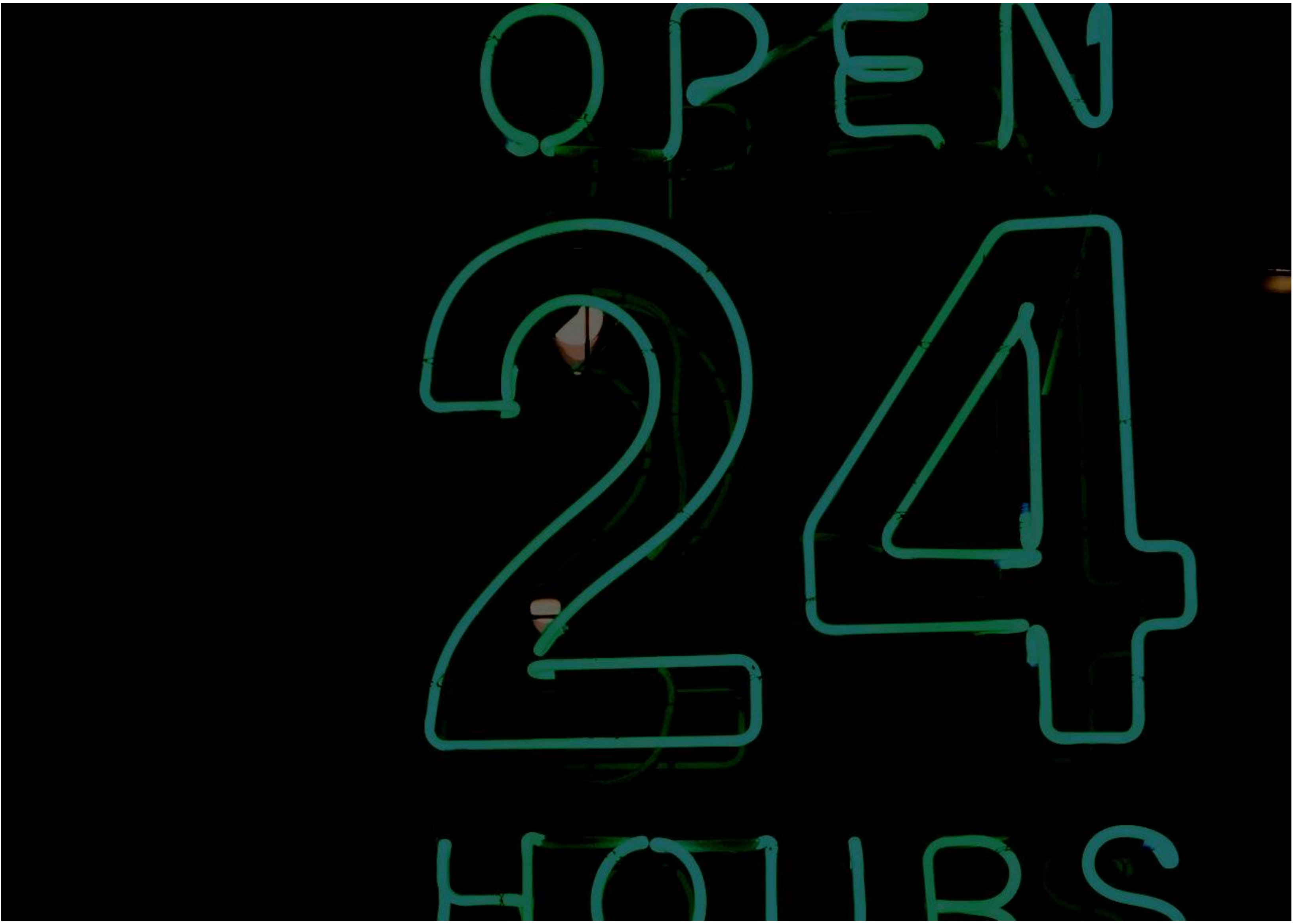
OPEN RAN 2019



Abstract: This report provides a forecast for how Open RAN standards will be used commercially. Will operators use Open RAN standards for fronthaul in their specs? Will they procure RU and DU equipment for 4G and 5G based on Open RAN and related eCPRI standards?

January 2019

MOBILE EXPERTS

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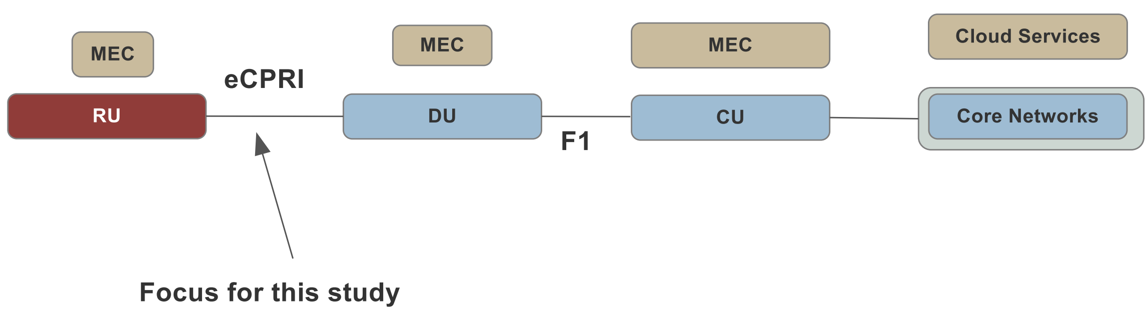
EXECUTIVE SUMMARY

The mobile industry is moving toward "openness". But the word "Open" can be defined in many different ways. The Internet ecosystem has benefited from the concepts of "open source" software, and the Cloud is built upon open standards so that many companies can contribute useful innovations. Mobile operators would like to duplicate this trend because they see the cost reduction potential in applying the lessons of the Internet web-scale market.

In the Radio Access Network (RAN), the first step will be an open standard between the Radio Unit (RU, also commonly called an RRH) and the Distributed Unit (DU, also known as the BBU in LTE). The industry will also develop a standard (the F1 interface) between the DU and the Central Unit (CU, covering the higher layer baseband processing for control path signals). These changes will allow for virtualization of the CU and/or DU, reducing the cost of hardware and software. Mobile operators believe that significant cost reduction is possible with open standards to enable replacement of individual network sub-systems.



Source: Mobile Experts

Figure 1. Basic 5G Network Diagram showing potential for standard interfaces

While the experts in the core network believe strongly in the potential for virtualization and commoditization of radio functions, the experts in the radio portion of the network are more skeptical. Mobile Experts interviewed more than 30 different organizations, to understand the upcoming decisions of mobile operators with regard to using a standard RU-DU interface. Most operators will admit that they plan to use the ORAN specifications and eCPRI to establish compatibility of different solutions, but they still have doubts about actually buying RU hardware separately from DU hardware.

Multiple organizations have been formed recently to pursue a standard RU-DU interface, but over the past 18 months these organizations have merged and coordinated with each other, so that the path toward an open standard is now pretty clear. The Open RAN Alliance will be taking the lead on development of an RU-DU interface standard, which will be much more comprehensive than the CPRI pseudo-standard. Other organizations in IEEE will support this work with eCPRI documentation, synchronization standards, and architectural/open source hardware reference designs.

It's clear that a standard will be developed. But after interviewing 20+ CTO-level executives, we believe that most mobile networks will not actually change their method for procuring base stations. Mobile operators will continue to buy the RU and DU from the same company, and their purchasing processes will continue to be bundled so that independent purchasing of RU and DU will not happen. Here are the reasons for sticking with single-vendor RAN solutions:

1. Each major RAN vendor has proprietary algorithms that support significant performance gains over a basic network that simply meets 3GPP standards. Many of these algorithms rely on coordination between RU and DU.
2. Operators want to ensure that, when problems arise, they can call one company to complain and get quick action to fix the problem. Operators fear that having different vendors for RU and DU would create big troubleshooting headaches.
3. A few operators expressed the opinion that interoperability testing would be expensive, especially since thoroughness in this kind of testing is difficult to achieve.

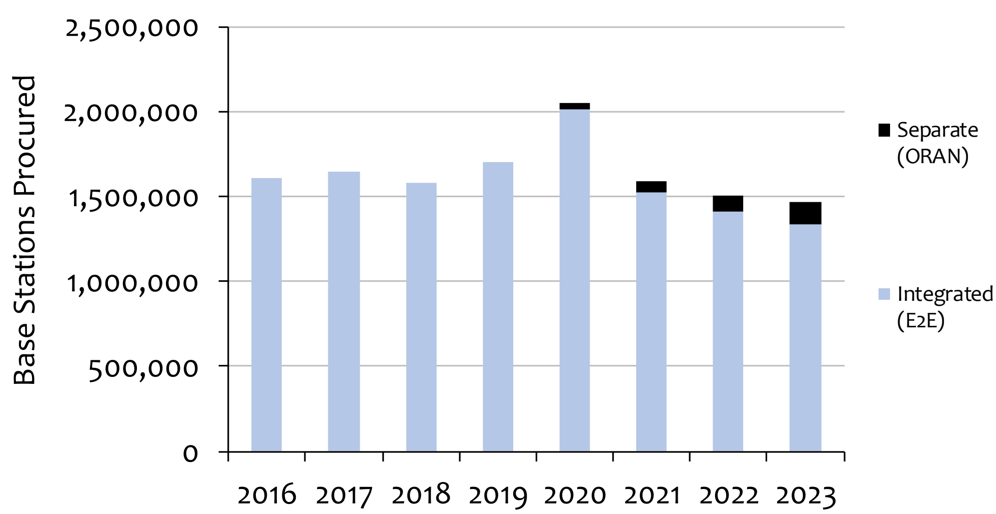


Chart 1: Global Base Station Shipments, ORAN procurement vs End-to-End procurement, 2016-2023

So, at the end of the day, we expect the top operators worldwide to use ORAN to specify their hardware, but then they will buy networks with RU and DU bundled together by the same OEM.

There will be a few exceptions to this rule:

- Cost-driven operators in developing countries may choose to buy RU and DU element separately, relying on the ORAN specification to guarantee a basic level of performance.
- Enterprises or neutral-host companies may use ORAN small cells inside buildings, in cases where high capacity is not necessary.
- Some operators are already forcing their vendors to share information about proprietary CPRI links, so that their existing inventory of RRH units and BBU capacity can be fully utilized. These operators are not deploying thousands of Vendor A RRH units and Vendor B baseband units, but simply want to be able to pair Vendor A and Vendor B on a case-by-case basis.
- Specialty radio units will be possible, such as unique beamsteering configurations or niche frequency bands that will be supported by third-party RU vendors. Again, these will be used by major operators on a case-by-case basis.

Overall, we believe that the market for independent RRH suppliers and software suppliers will be limited during the next five years. It's possible that we will see this low-cost segment of the market expand over time, but during the next five years we don't expect the major thrust of the market to move toward free competition in separate RU and DU elements.

MARKET DRIVERS AND CHALLENGES

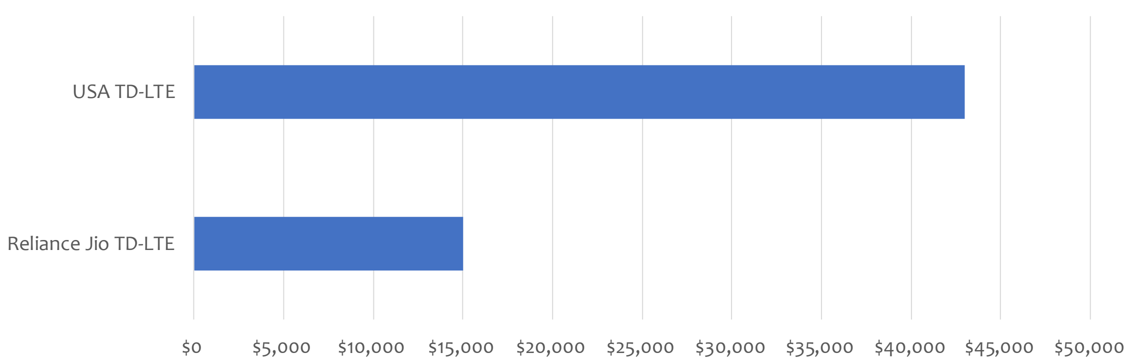
Why is the industry moving toward open networks, open-source software, virtualization? What are the driving forces behind the groundswell of support for these efforts across multiple areas of the network?

Cost

Mobile operators feel that their RAN hardware is overpriced. They buy dedicated hardware for radio and baseband processing functions, paying 4-5X higher prices than the web-scale players pay for similar levels of computing power and software.

The pricing issue is especially painful when operators can see other markets where lower prices prevail. Specifically, the LTE network at Reliance Jio was deployed for about 80% lower cost per base station, with Reliance Jio using Samsung and Airspan equipment heavily instead of major RAN vendors. From the outside, the Reliance Jio network appears to be working, so this huge cost difference created a lot of anger toward Nokia and Ericsson for charging "excessive" prices.

So, saving money is the strongest rationale for creating open standards for freely interchangeable network elements. If the operators can succeed in creating true interchangeability, their network cost can drop in half or even more.



Source: Mobile Experts

Figure 2. Anecdotal Price Comparison for 20 MHz TD-LTE Base Stations in 2017

Flexibility and Inventory Issues

Mobile operators feel stuck with a single vendor with their mobile networks. Because software and hardware are not interchangeable between vendors, they have no choices when it comes to upgrades and support.

In everyday network operations, the decision to use a single RAN vendor is understood and everyone goes along as a matter of course. However, in transitions the lack of interoperability can create some headaches.

For example, when a network operator makes a change to include a new RAN vendor in a small region (as Verizon has done recently with Samsung in their LTE network), they find that upgrading network elements must be coordinated in time. The Remote Radio Heads and BBUs must be changed simultaneously, making the logistics for an upgrade more expensive and complex.

Also, any inventory of radios or baseband processors cannot be re-used. If the operator chooses to install a new baseband processing vendor in order to enable a new feature, pre-existing radio heads cannot be re-used. Even sites that don't have critical capacity requirements must be changed along with the impacted sites.

Troubleshooting

One major challenge to the adoption of "mix and match" networks stems from the need for mobile operators to troubleshoot when networks don't perform as well as expected. Who to blame? Is it the baseband processing or the radio? The finger-pointing can be endless when KPIs are not met.

Most major mobile operators with more than 10 million subscribers have already learned this lesson with 2G/3G/4G networks and complexities between vendors in each generation. In our interviews, the experts do not believe that 3GPP standards are developed thoroughly enough to isolate performance issues to a simple, single root cause.

For this reason, we anticipate that top-tier networks in North America, Western Europe, Japan, Korea, and China are not likely to procure radios or baseband processing according to ORAN standards…instead they will buy the entire network in one RFP process.

OEM resistance

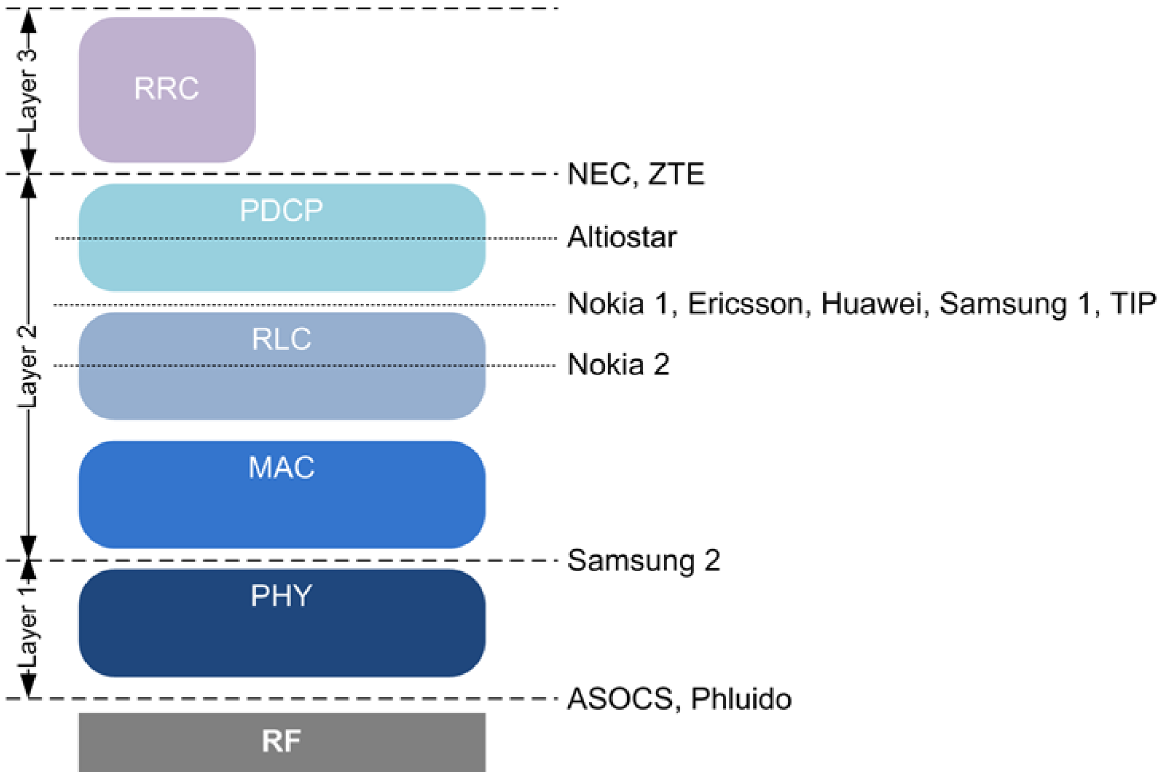
During the development of OBSAI and CPRI in 2002-2004, the major RAN vendors took over the management of the standards organizations. Ericsson employed the chairman of the CPRI Alliance, and Nokia Networks employed the chairman of the OBSAI Alliance. In both cases, the OEMs were able to successfully divert these standards groups away from developing effective standards.

In the case of CPRI, the working groups were able to define a serialized data protocol which is now universally used across the mobile industry. So, in one sense we can say that CPRI was successful. However, due to the intervention of the OEMs, only the serialized RF data is standardized, and the Operations & Management (O&M) functions are not included in CPRI specifications.

The O&M functions are very simple. They include alarms that detect whether an antenna is present, over-temperature monitoring, failure monitoring, and several other alarms or adjustments to ensure that the radio site is working properly. Every major OEM uses its own proprietary communications for O&M. So, if an operator tries to plug Vendor A radios into a Vendor B network, the details of the alarms will not be reported properly to the baseband processor, and the BBU will command the radio to shut down. The BBU will stop sending I/Q data along the CPRI path. Everything stops.

In this way, the OEMs achieved their goal to preserve a proprietary lock on the hardware for the network. Nokia, Ericsson, Huawei, and ZTE have continued to sell their proprietary hardware within their footprint without competition for the past 15 years.

Today, the OEMs say publicly that they support open networks, but many industry experts are skeptical. Would the RAN vendors really benefit from opening up the RAN interface? Yes, they are actively pursuing virtualization now and we expect them to work with standard x86 servers for non-real time baseband processing functions. But each OEM has a different idea about the ideal partitioning of the baseband stack.



Source: Mobile Experts

Figure 3. Each OEM's choices of the best baseband partitioning

To preserve their differentiation in the software stack, there are some basic things about the partition in the baseband stack, and the location for each processing function, that will be unique to each OEM. This will be a source of resistance to the general idea of standardizing the fronthaul into one standard.

Further differentiation will require communications between the radio and baseband processing, to coordinate things such as PIM cancellation, beamsteering optimization, EVM enhancement, power optimization through envelope tracking, and other digital signal processing functions. So, the OEMs will insist on having a way to communicate proprietary information between the RRH and the BBU.

One possible compromise will come in the eCPRI specifications, where a proprietary channel will be allowed on top of the standard packetized data stream and O&M signaling. We haven't seen how this will be implemented in detail yet, but multiple players mentioned this as a feature of upcoming specifications.

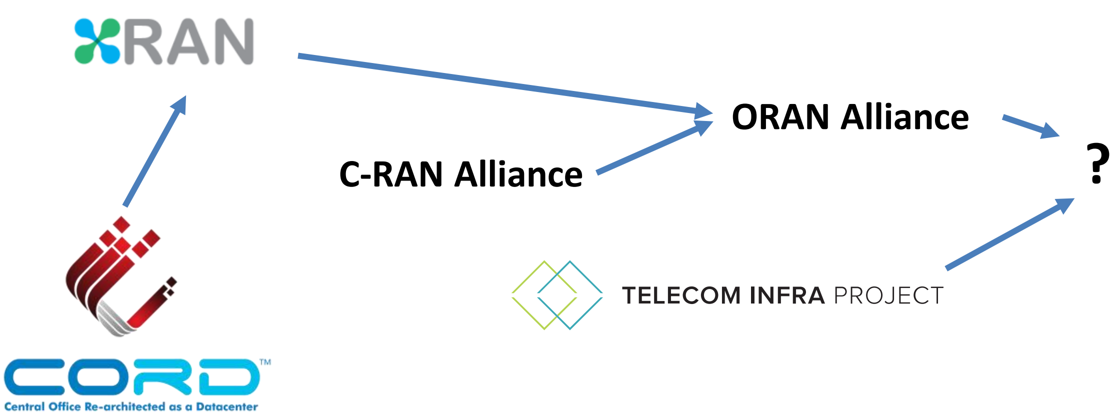
The resistance of the OEMs should not be discounted. It's politically correct for them to publicly support "openness", but when we get into the details, their business differentiation will win the day. Keep in mind that there are 4-5 major RAN vendors, and hundreds of customers….this means that each customer individually has poor leverage to force a true standard.

TECHNOLOGY OVERVIEW

Multiple groups have formed over the past five years, all with the same fundamental objective to reduce RAN cost. Over time, many of these groups have decided to merge together because almost everyone recognizes the need for a unified specification to achieve acceptance of the new standard.

Many different alliances and initiatives

Technology initiatives for Open RAN include several different organizations as well as private initiatives for individual operators. This confusing group of different organizations is actually becoming much more clear over the past six months, as we see all of these organizations converging.



Source: Mobile Experts

Figure 4. Convergence of Multiple Open RAN organizations

At this point, it's not really clear which organizations will take the lead on specific aspects of open interfaces, or whether multiple variations will coexist. All of these organizations are small and are lightly held by their founder companies… in other words, we don't see major barriers to a complete consolidation of these to arrive at a single interface for the RAN. We are likely to see these groups continue on, as they develop specific solutions for their individual focus markets.

For example, Facebook is interested in developing a reference design for low-cost rural LTE network hardware. Facebook can use the Open RAN Alliance standard but will continue to develop hardware reference designs in their attempt to achieve low cost.

Initiative	Launch Date	Goal	Status
Telecom Infra Project (TIP)	February 2016	Multiple goals	OpenRAN group led by Vodafone/Intel to develop APIs, orchestration….then test FPGA-enhanced x86 servers
xRAN Forum	October 2016	Open RRH/BBU interface	Merged with ORAN Alliance, February 2018
C-RAN Alliance	Nov 2016	Virtualization and open interfaces	Merged with xRAN Forum to form ORAN Alliance, February 2018
Open RAN Alliance	February 2018	Open RRH/BBU interface	Growing support of operators. Released open fronthaul spec in April 2018
Open vRAN Initiative (Cisco)	February 2018	Open interfaces	Coordinating with ORAN Alliance
NGMN		Fronthaul architecture	Released v0.6.5 framework in May 2017
eCPRI	Roughly 2016, work within CPRI Alliance	Interface Specification	Released V1.1 Jan 2018, started developing V2.0 to be released in 2019

Source: Mobile Experts. NOTE: Focus here is on RU-DU interface

Figure 5. Details of multiple Open RAN organizations

In addition to the newly established non-profit organizations, a few private initiatives are notable here as well.

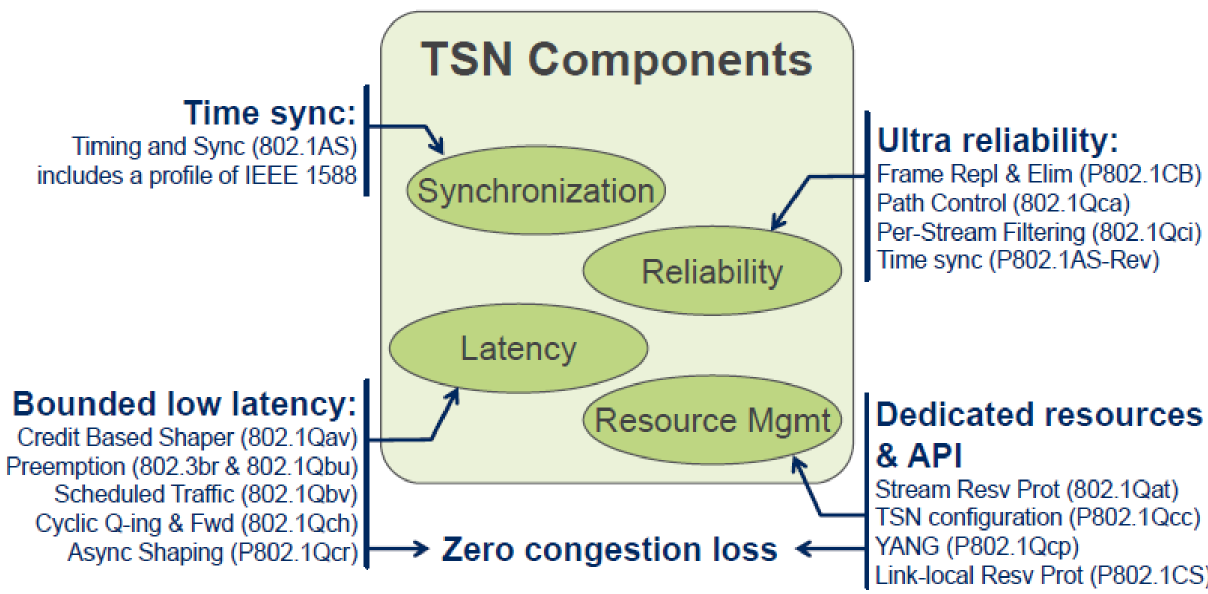
- Verizon has successfully forced their vendors to interoperate. During early 2018, Verizon managed to force Nokia and Ericsson into providing protocol information for their proprietary CPRI Operation and Management (CPRI O&M) communications. This means that when Samsung enters as a new vendor, Verizon has the option to plug a Samsung radio unit into a Nokia or Ericsson BBU. In the past, despite the standardization of CPRI, the O&M interface was proprietary, and the lack of a handshake between RRH and BBU would shut down the radio.

- SKT has developed its own Open Fronthaul Interface, which it has labeled the Fx interface. They've pushed this specification through the Korean Telecom Technology Association (TTA). SKT has aggressive 5G deployment plans for early 2019, so this step was important to them in forcing suppliers to quote lower prices.

The Interface specifications

Multiple specifications have been developed so far to govern the interface between RRH and BBU. Because the distinct organizations creating these specifications are all merging together, we anticipate that these interface specifications will also converge to a more coherent set of documents:

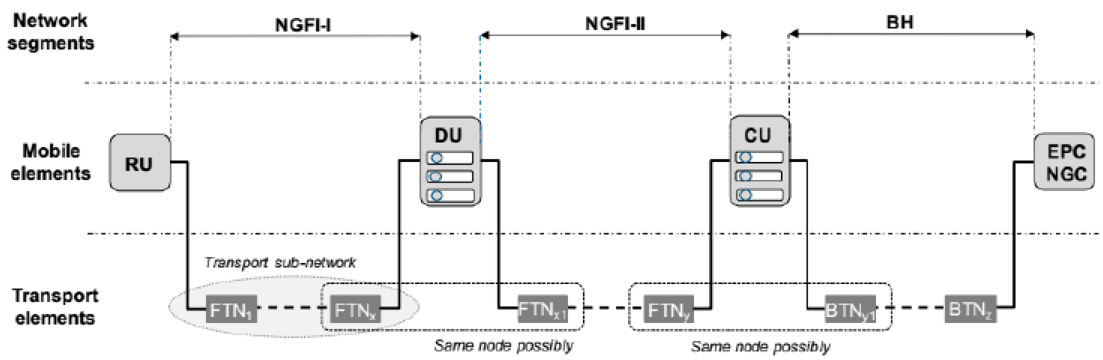
- 802.1: Time sensitive networking working group, governed by IEEE. This group sets critical specifications related to time synchronization in the interface.



Source: IEEE 802.1

Figure 6. Overview of IEEE 802.1 components

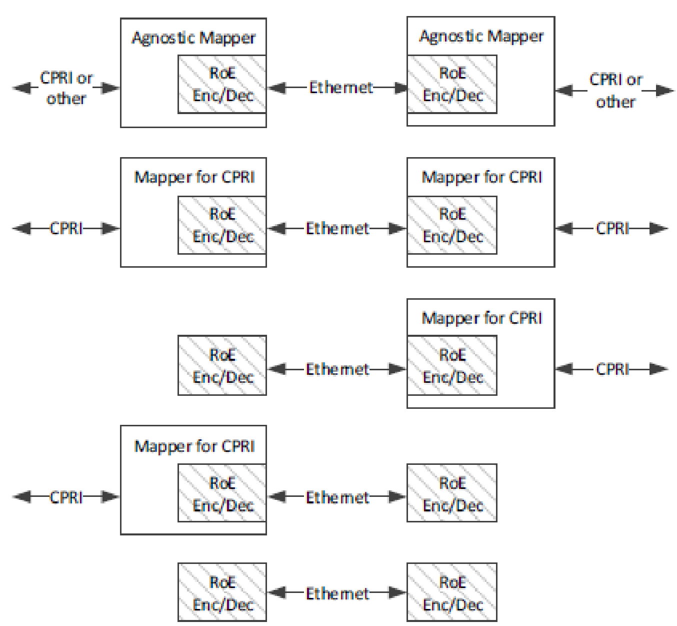
- 1914.1: This IEEE working group is developing standards for packet-based fronthaul. Established in May 2016, the group's goal is to establish the architecture for using IP packets instead of serialized data for mobile fronthaul. The group evaluates multiple fronthaul partitioning options so it's not likely to result in a single format in terms of data rate, timing, synchronization, etc. Specification D0.4 was released in September 2017. IEEE 1914.1 defines the overall model of "Fronthaul-I" or NGFI-I, connecting the RU to a DU; "Fronthaul-II" or NGFI-II, connecting the DU to a CU, and Backhaul to connect the CU to the core.



Source: IEEE 1914.1

Figure 7. Overall fronthaul and backhaul network model for IEEE

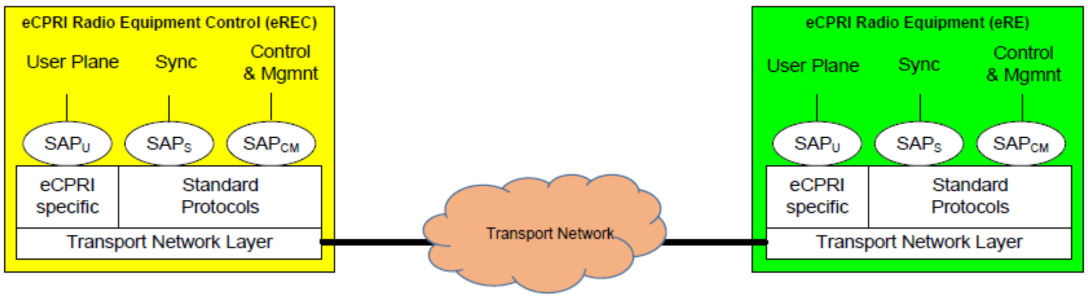
- 1914.3: Radio over Ethernet is developed by the IEEE 1914.3 working group, as this standard defines the encapsulation and mapping of radio transport over Ethernet frames. Specification D2.1 was released in late 2017. The idea is to allow a CPRI stream to tunnel agnostically through an Ethernet network. The 1914.3 group focuses on 3GPP functional splits 8, 7.2, and 7.1



Source: IEEE 1914.3

Figure 8. CPRI tunneling over Ethernet

- eCPRI: The CPRI Alliance released specification V1.1 in January 2018, laying out the exact format for user plane data, synchronization, and control/management functions. The eCPRI specification assumes that the transport network between the BBU and the radio conforms to the requirements laid out in 802.1 for time-sensitive networking. Otherwise, eCPRI is agnostic to the physical transport approach. Based on eCPRI development so far, we expect it to include provisions for a proprietary channel, so that basic operation is fully standardized but each vendor can add its 'secret sauce' when it provides both DU and RU.



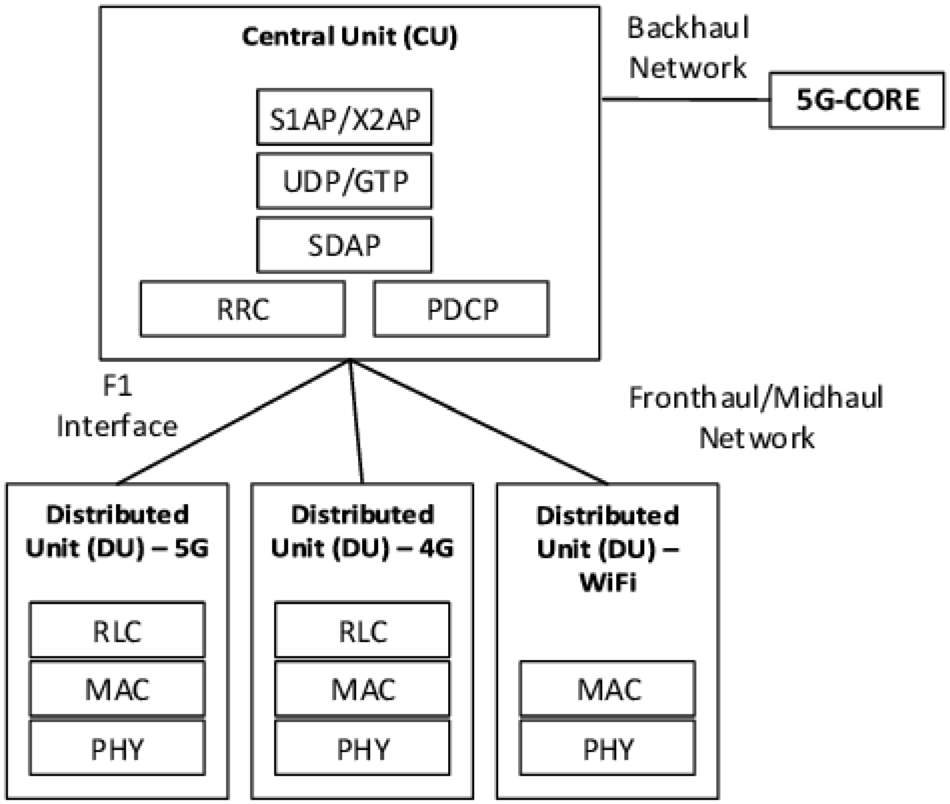
Source: CPRI Alliance

Figure 9. Overview of eCPRI architecture

- xRAN/ORAN: The xRAN Forum developed a fronthaul specification (XRAN-FH.CUS.0-v02.00) which was released in July 2018. The xRAN spec covers the Split 7.2 architecture for Control, User Plane, and Sync, with plenty of references to IEEE specifications and eCPRI specifications. Our view of the relationship between ORAN and eCPRI is not fully clear today, but it appears that ORAN will add details that are missing in the OEM-dominated eCPRI standard to ensure interoperability.

The F1 Fronthaul interface

Most of this report focuses on the RU-DU interface, but in the emerging 5G architecture the baseband processing and data flows are split into three locations instead of two. The RU resides on the tower, the DU is within a few kilometers, and the control plane functions (non-real time functions such as PDCP, SDAP, RRC) can be located hundreds of kilometers away. This allows for centralization and virtualization of the CU functions.



Source: Nokos Makris, et al. ICC Conference

Figure 10. Functional Diagram for F1 interface in a 5G/LTE/WiFi network

Several operators have commented that the F1 interface (as developed within 3GPP) is likely to become more fully standardized than the RU-DU interface, because of the non-real time nature of the communications. The operators see F1 as more of a "commodity" interface and they are keen to have interoperability at this level to encourage more competition, even when they do not expect to do so at the radio level.

The F1 interface can be seen as the next generation of the S1 interface used in 4G networks, connecting a BBU to an evolved packet core. Because of the historic use of S1, we expect a very high level of standardization for F1.

Key Features in the Standards/Interfaces

So, as described above we have a collection of IEEE working groups and alliances that are developing standards. This part is very similar to the development of CPRI and OBSAI standards in 2003, when the industry settled into proprietary CPRI product usage. What will be different this time?

The original CPRI and OBSAI initiatives failed to achieve interoperability purely because the OEMs prevented it. While the working groups focused on a standard serialized data stream, each of the OEMs developed its own separate O&M layer for the CPRI and OBSAI interfaces. As a result, when the standards were finished, each vendor continued to have a barrier such that no competing products could be plugged into their network.

This time, the operators are paying attention to the O&M layer, swearing not to fall for the same trick again. So, with the eventual implementation of eCPRI we expect that basic functionality will be supported. Any eCPRI-compliant network element will work.

The major RAN vendors remain very focused on differentiating their products, so they will insist on keeping a proprietary channel in eCPRI. The proprietary channel will allow them to pass information between RU and DU to coordinate non-standard features. Examples could include things such as inter-cell interference algorithms, PIM cancellation, or beamsteering corrections. The value of these proprietary algorithms is the main topic of this report….essentially, we aim to evaluate how much performance enhancement is available with proprietary coordination, compared with a basic standards-compliant network?

PERFORMANCE FACTORS

A key question in the ORAN community is: How well does a network perform, if distinct vendors are chosen for each network element, and there is no non-standard-based coordination between the RRH and baseband processing?

Performance in vRAN trials

We've seen a few examples of how a generic RRH can work with a virtualized BBU:

1. Intel has engaged in multiple field trials, testing generic radio hardware with a fully virtualized baseband stack (baseband operating on an x86 server with standard FPGA accelerator card). Reportedly, the performance of this generic hardware configuration is similar to typical LTE networks but we don't have hard data for comparison.
2. Mavenir has also tested their virtual baseband stack at KT and Vodafone, using multiple RRH vendors, and in fact has set up relationships with at least 10 different radio suppliers. MTI, Tecore, Baicells, NEC, AceAxis, KMW, Benetel, CommScope, Blue Danube, and Airrays are all collaborating with Mavenir for interchangeable radio hardware using xRAN Option 7.2. Despite the lock to a common Ethernet Fronthaul specification, each vendor nonetheless can be differentiated by using different power levels and antenna configurations.
3. Altiostar has conducted trials with TIM, SKT, and other unnamed operators, as well as integrating their vRAN solution with DAS and other radio solutions.

In all of the above cases, we have received very positive reports about the functionality. Virtualized RAN works. The question is "how do we compare the KPIs of a generic network to a fully optimized, single-vendor end to end network?" In our discussions with Intel, Altiostar, ASOCs, Parallel Wireless, Mavenir, and others, we have not been able to find any hard data to illustrate high-density network performance. In short, nobody knows whether these networks can achieve high density (Gbps/km2/MHz) with low error rates, because to our knowledge nobody has conducted a trial under heavily loaded conditions in a commercial urban network.

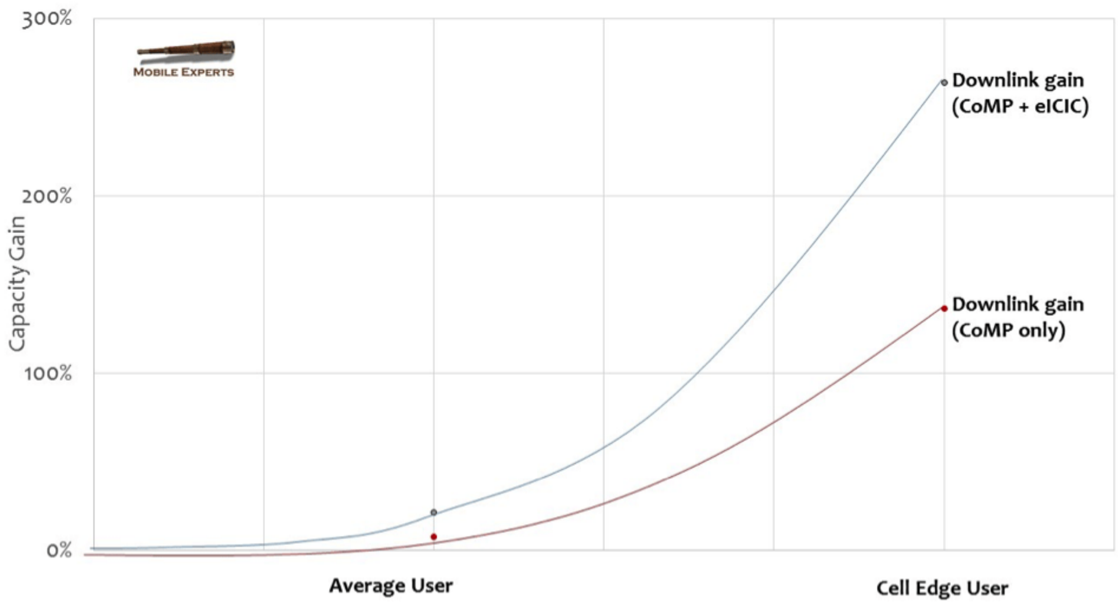
Learning from Prior History in 2G thru LTE

One data point can be instructive here. When Nokia merged with Alcatel-Lucent, the Nokia baseband processor was applied to the existing ALU LTE radios in the field. Without any other changes, there was a substantial improvement in performance. Capacity increased by roughly 25-30% due to improved coordination and scheduling in the baseband processors. Note that this improvement did not rely on any communication between the RRH and the BBU….it simply resulted from improved algorithms within the BBU itself.

Notably, the Nokia/ALU improvement was duplicated recently when Samsung BBUs were applied to legacy ALU remote radio heads. This implies that the ALU baseband processing function was not performing at high levels, and other groups have better algorithms for scheduling and coordinating traffic.

Mobile Experts has surveyed multiple CTO-level contacts across the industry, to estimate the potential impact of inter-cell coordination. We received estimates that varied widely:

- 2G networks were often improved by adding radio upgrades such as TMAs or 'booster' power amplifiers from third parties;
- 3G networks did not lend themselves to capacity or interference coordination between sites, so a 'standards based' approach would have been similar to the performance of an 'optimized' network;
- In LTE, features such as CoMP and eICIC can improve performance marginally when implemented according to standards, estimated by one engineer to be only 5%. Proprietary tweaks can increase the benefit of these features to about 20% capacity boost overall, or up to 50% benefit over generic networks at the cell edge.
- We published analysis of field trials conducted by Airspan and Softbank in 2015, in which special attention to inter-cell coordination improved CoMP/eICIC performance by more than 100%. This trial, conducted under heavily loaded conditions in a live network, illustrated that proprietary techniques by a single RAN vendor can dramatically enhance the outcome of standard features such as Joint Transmission and Interference Coordination. Specifically, in the downlink Softbank measured 250% throughput gain at the cell edge, while previous "standards-based" tests had indicated about 50% benefit from Joint Processing/eICIC.



Source: Softbank/Airspan, Mobile Experts

Figure 11. Measured Benefit of Coordination between Radios

New challenges with beamforming and massive MIMO

The capacity benefits of 5G largely rely on the use of massive MIMO for higher spectral efficiency. After all, the 5G NR waveform has less than 20% impact on spectral efficiency over the LTE waveform in terms of raw performance… but the use of high-order MIMO can increase spectral efficiency from roughly 1-2 bps/Hz to 6-8 bps/Hz.

Therefore our focus in looking at 5G networks must be to evaluate whether beamforming and multi-user MIMO will depend on coordination between radio sites.

Where LTE can be enhanced through coordination between multiple radio sites, beamsteering appears to be even more fertile soil for improvements. Multiple factors related to beamsteering are not covered in 3GPP standards, but are critical to performance:

- Overlap between beams directly reduces the spectral efficiency of multi-user MIMO. The radio vendor must take special care to create beams which barely overlap for successful handoffs, but which don't overlap enough to significantly reduce capacity.
- Most trials of massive MIMO so far have used isolated sectors, and early tests of multi-site massive MIMO deployment experienced strong, unmanaged inter-cell interference. Recent improvements have been implemented by

specific vendors outside of 3GPP standards, to make inter-site beamsteering interference manageable.

- Mavenir has created a 'beamforming control interface group' in which multiple RRH vendors agree to standardize controls for the beamsteering array. We don't know yet whether this will be effective, given the wide variety of steered antenna designs.
- One RAN vendor CTO estimated the enhancement from "proprietary algorithms" to be 100% for massive MIMO networks.
- Another RAN vendor CTO estimated the enhancement to be 70%, considering algorithms that require coordination between the radio and a centralized digital unit.

Overall, these estimates cover a wide range…but it seems clear that the level of capacity benefit from inter-cell coordination increases dramatically with the use of OFDM and massive MIMO. For comparison, we've placed the benefit at 55%, near the middle of our survey results.

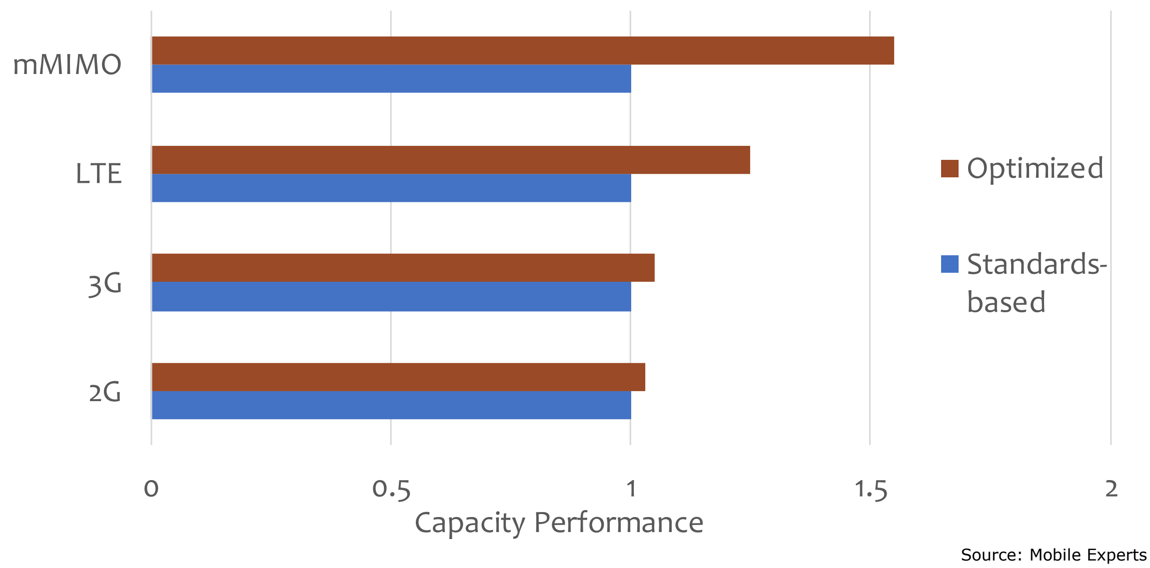


Figure 12. Measured Benefit of Coordination between Radios

Comments from mobile operators

Mobile operators are driving the initiatives for Open RAN, but what will they really buy? There are a few comments that we can collect here:

- Bill Stone from Verizon commented publicly, that multi-vendor networks increase complexity dramatically, and he prefers to 'limit complexity and not to use nine different vendors'.

- Verizon has also forced Samsung, Nokia, and Ericsson to share specifications with each other, to enable interoperability using proprietary CPRI fronthaul. The Verizon engineers in regional deployment do not consider this to be enough reason to routinely pair Vendor A radios with Vendor B baseband… but they consider it to be helpful in managing transitions and excess inventory.
- Another major American network operator CTO told Mobile Experts that "tight system integration is required within and between base stations. ORAN would likely reduce gains to the 'least common denominator'," which would not achieve the desired high-density performance in the urban center.
- One Japanese mobile operator commented that they view ORAN as a way to keep vendors competitive, but not necessarily as a path toward 'mix and match' vendors.
- A second Japanese operator commented that they do not plan to use ORAN to buy separate RU and DU products, but they will use the F1 interface to enable virtualization of the CU independent of vendor choice.
- One European operator mentioned that while ORAN is promising for cost reduction, they are reluctant to use a different 5G RAN vendor than their existing LTE network, to ensure that LTE and 5G work in Non-Stand-Alone configuration seamlessly.
- Vodafone has recently completed an RFI related to ORAN, and acknowledged high performance by a few vendors, highlighting Mavenir, Parallel, and Altiostar as the "most compliant end-to-end platforms", as well as ASOCS and Phluido as "innovators". Vodafone will be trialing networks from Parallel Wireless in Turkey, and from Altiostar/Mavenir in Africa through March 2019.
- Telefonica announced three pilot deploymnets with Mavenir, Altiostar, and Parallel Wireless in Latin America during early 2019.

So, despite the strong business rationale to use ORAN-based hardware to reduce cost, in private discussions we hear a lot of doubt and reluctance by the operators. The world-leading operators will not necessarily change from 2-3 vendors to 9-10 vendors… but they do want the competitive pressure, and they want the ability to use leftover assets that don't match at the fringes.

Important Features of the ORAN interface standards

As the industry wraps up specifications for the RU to DU interface, a few key features will be extremely important to individual players:

1. The serialized I/Q data of the old CPRI format will be changed to a packet-based format, where real-time processing is executed in the RU, and non-real time functions are executed in the DU or CU. This format needs to be flexible, as the baseband partitioning is not settled and multiple baseband splits must be supported. Each baseband split (from Option 2 to Option 3

and Option 7, among others) have different requirements for jitter, throughput, and synchronization.

2. Operators will insist on standardizing the Operations & Maintenance functions of the interface. For CPRI and OBSAI, the O&M functionality rendered the entire standardization effort meaningless…and the operators are determined not to miss such an obvious part of the interface spec.
3. OEMs will insist on a proprietary channel so that they can communicate in real time between the RU and the DU. Each OEM has proprietary ideas that involve some coordination between these network elements, and they have created a separate channel within the xRAN/ORAN concept for their 'secret sauce'.

Without any of these major elements, the ORAN standardization process will break down. So we conclude that all three will be included in the final product.

Reality Check: Current Networks

At a high level, if we compare two major LTE networks we can gain some understanding about the importance of network optimization. There's a major difference between a standards-compliant network and an optimized network.

As an example, we examine China Mobile and Verizon.

	China Mobile	Verizon
Number of Subscribers	900 million	150 million
Number of Sites	1.7 million	75,000
RF spectrum	195 MHz	110 MHz
Avg Capacity per site	300 Mbps	220 Mbps
Total Capacity	510 Tbps	16 Tbps
Capacity available per user	0.6 Mbps	0.1 Mbps
Actual usage per subscriber	3 GB/month	7 GB/month
Actual Utilization of Theoretical Capacity	0.002%	0.02%

Source: Mobile Experts

Figure 13. Comparison of China Mobile and Verizon networks for capacity utilization efficiency

So, China Mobile has a huge investment in capacity, with a theoretical level of 510 Tbps available….but CMCC customers actually use less data than American customers currently. The difference in actual utilization of the network is a factor of 10 difference.

Having excess capacity is no problem, and certainly we don't find any fault with China Mobile for building out extra capacity. However, the quality of LTE services is also better at Verizon than at China Mobile. Actual KPI data are not available, but it's clear that the dropped call percentage and frame error rates are superior on the Verizon network.

There's no way for an outsider to determine the root difference between China Mobile's performance and the performance at Verizon, but this example illustrates very clearly that following the 3GPP standards is not enough….optimization of the network is critical to achieving the capacity that is expected.

COST/BENEFIT ANALYSIS

Clear evidence now exists in the market to illustrate the cost savings associated with open interfaces, higher levels of competition, and open-source software. But at the same time, we see multiple indications that a single end-to-end vendor with proprietary techniques can achieve higher performance.

This section aims to weigh the cost savings of ORAN against the performance advantage of a proprietary network. Is the benefit worth the cost?

Estimates of Cost Savings

Based on the differences in network CAPEX and OPEX costs between different world markets, we have clear indications that more open competition would dramatically change the cost of the network.

Here are some data points:

1. Mavenir promises a 49% savings in CAPEX, and 31% savings in OPEX for operators that implement their virtualized network with third-party RRH units.

2. Reliance Jio buys TD-LTE macro base stations (including BBU and three RRH units) for $15,000 in India as of early 2018. The equivalent price for Sprint in the USA is $43,000 for the same hardware and software. Note that Sprint's data point is based on lower volume since Jio bought roughly one million base stations over a two-year deployment.

3. Verizon has started to deploy Samsung LTE macro base stations in the US market, citing more than 50% lower CAPEX cost as the key reason.

Based on these three data points, we believe that 50% CAPEX savings and 30% OPEX savings are realistic for an ORAN network compared with a Nokia or Ericsson network.

Financial Impact of Performance Benefits

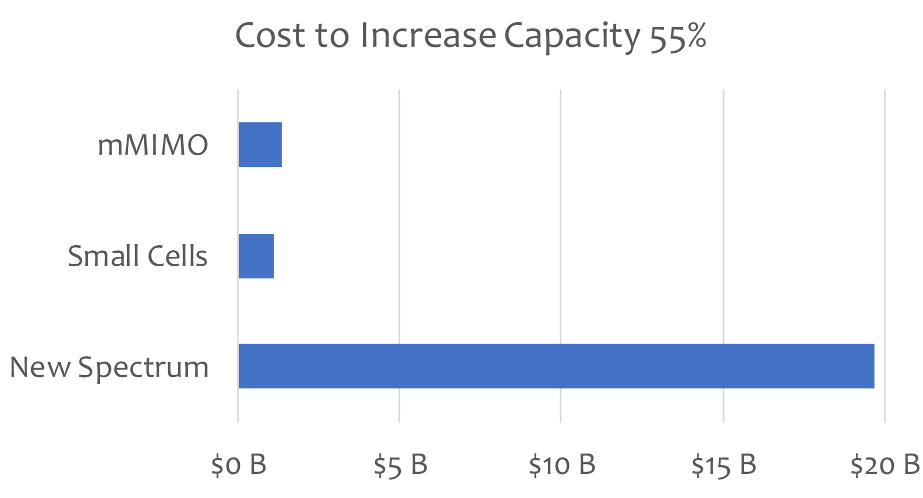
In a previous section, we estimated the performance benefit as 55% higher capacity for an LTE network optimized by a single vendor's software. To calculate the financial impact of this benefit, we look at specific alternatives to add 55% more capacity:

1. More Spectrum: This is not really a realistic scenario for operators, since spectrum is not available so easily in many places….however, considering the cost for spectrum, network equipment, backhaul upgrades, tower leases, energy, and other factors, the 8-year Total Cost of Ownership would total some $34 billion to add 55% capacity to a major US network. Assuming the use of massive MIMO, less spectrum would be needed, reducing the total cost to roughly $28 B.

2. Small Cells: Adding 55% more capacity through small cells would cost $1.1 billion for a major US network. This alternative is also problematic, because more than 32,000 small cells would be required (each with 4-5 bands plus LAA). Such high numbers of small cells are difficult to deploy evenly throughout a network in the USA or Europe due to government restrictions.

3. Massive MIMO: Upgrading the existing macro network to Massive MIMO can also add capacity. In our example in the USA, we assume that m-MIMO can increase spectral efficiency from 2bps/Hz to 6 bps/Hz, so roughly 20,600 base stations would need upgrades at a cost of more than $1B.

It's important to note here that mobile operators are already installing as many small cells as possible, as well as upgrading networks for new 5G spectrum and Massive MIMO. So, while we can calculate the "value" of adding more capacity to be at least $1 billion, the operators are already spending this money to keep up with demand growth. It's not realistic to substitute these three alternatives for an ORAN network, so our calculations are simply a way to estimate the value of additional capacity.



Source: Mobile Experts

Figure 14. Cost of three alternatives for additional capacity

Greenfield case—capacity limited

To summarize, we estimate that proprietary networks will achieve 55% higher capacity than equivalent ORAN networks. But the ORAN network can be 50% cheaper in terms of CAPEX and 30% cheaper in OPEX.

In a greenfield network, these two factors offset each other. Each site provides lower capacity, so 55% more base stations must be deployed. Since each base station is cheaper by half, building 77,500 ORAN base stations is still cheaper than 50,000 standard base stations. However, the network equipment is not the only cost involved. New backhaul, site acquisition, and power requirements will quickly overwhelm the savings associated with the network equipment itself.

	Number of sites	Base Station cost	Site Acq cost	Backhaul CAPEX	8 year OPEX	**Total cost**
Proprietar	50,000	$ 30,000	$ 25,000	$ 25,000	$ 120,000	**$10,000 M**
ORAN	77,500	$ 15,000	$ 25,000	$ 25,000	$ 84,000	**$11,548 M**

Source: Mobile Experts

Figure 15. Cost Comparison: Capacity Limited Proprietary and ORAN networks

Greenfield case—coverage limited

Of course, if capacity is not an issue, then the equation changes. An ORAN base station's coverage is dictated simply by the radio power and antenna setup, not by fancy coordination between sites. Therefore in a rural network that is coverage-dominated, the ORAN network would actually be cheaper.

	Number of sites	Base Station cost	Site Acq cost	Backhaul CAPEX	8 year OPEX	**Total cost**
Proprietar	50,000	$ 30,000	$ 25,000	$ 25,000	$ 120,000	**$10,000 M**
ORAN	50,000	$ 15,000	$ 25,000	$ 25,000	$ 84,000	**$7,450 M**

Source: Mobile Experts

Figure 16. Cost Comparison: Coverage Limited Proprietary and ORAN networks

In third-world markets where site acquisition and backhaul costs are low, the difference could be much higher than shown above. Considering a small African country with a need for 10,000 rural sites, the ORAN option is pretty attractive at only 62% of the cost of a proprietary network.

	Number of sites	Base Station cost	Site Acq cost	Backhaul CAPEX	8 year OPEX	Total cost
Proprietar	10,000	$ 30,000	$ 2,500	$ 5,000	$ 8,000	$455 M
ORAN	10,000	$ 15,000	$ 2,500	$ 5,000	$ 5,600	$281 M

Source: Mobile Experts

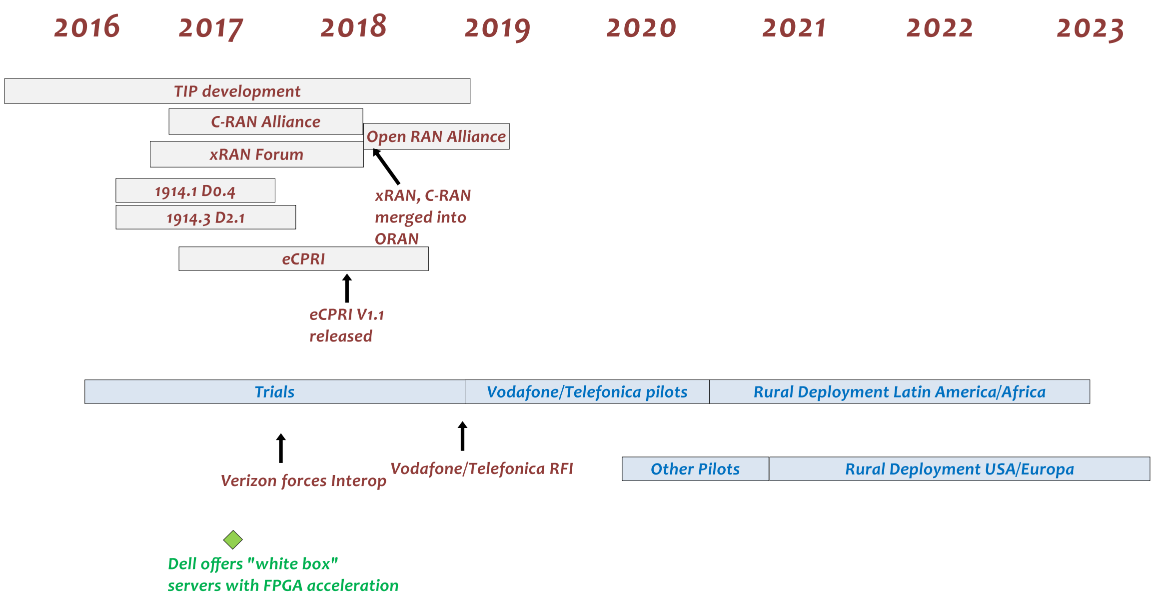
Figure 17. Cost Comparison: Proprietary and ORAN networks in Developing Markets

TIMELINE

The industry has reached an interesting point in time, where trials have been underway for some time, and multiple standards organizations and alliances have now released specifications.

Vodafone and Telefonica have taken the extraordinary step of a very public RFI process in which they stated their objectives and selected three companies for pilot programs in their emerging-market networks.

We believe that the market will be moving toward deployment of small numbers of ORAN base stations in the 2020-2021 timeframe, with a focus initially on Latin America and Africa. Eastern European and North American networks (in rural areas only) could follow soon after.



Source: Mobile Experts

Figure 18. Timeline for ORAN market development

MARKET FORECAST

As we consider the market shifting from LTE to 5G in some countries, and ongoing LTE investment in other countries, we have a few segments where ORAN based procurement is more likely to happen.

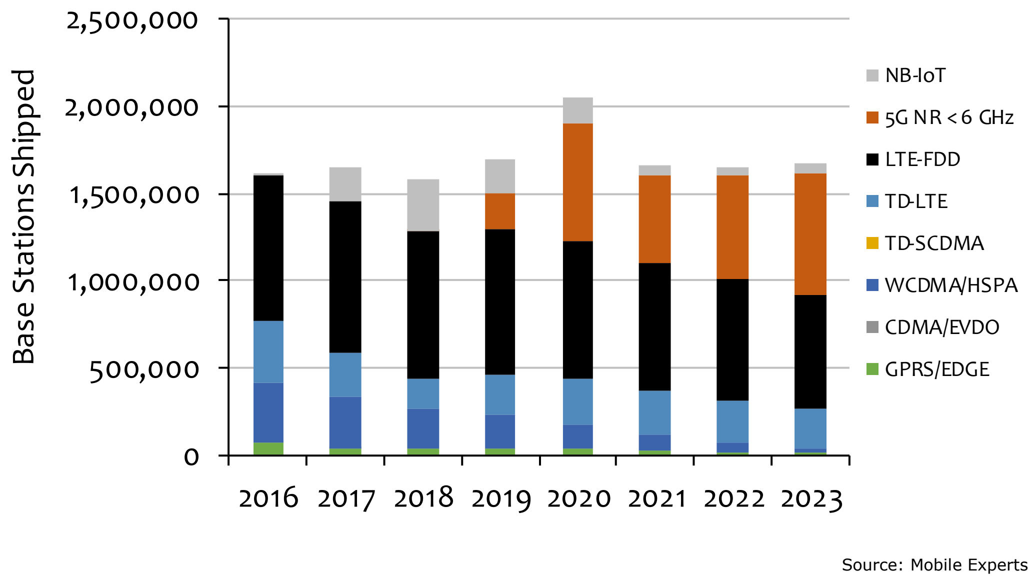


Chart 2: Global Base Station Shipments, by air interface, 2016-2023

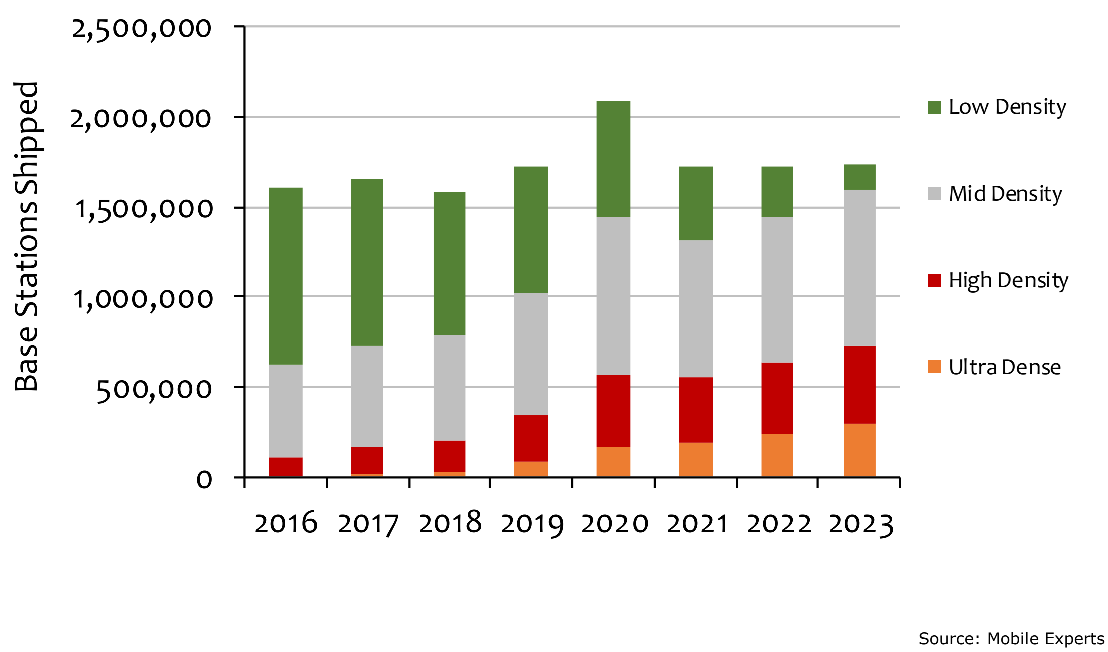
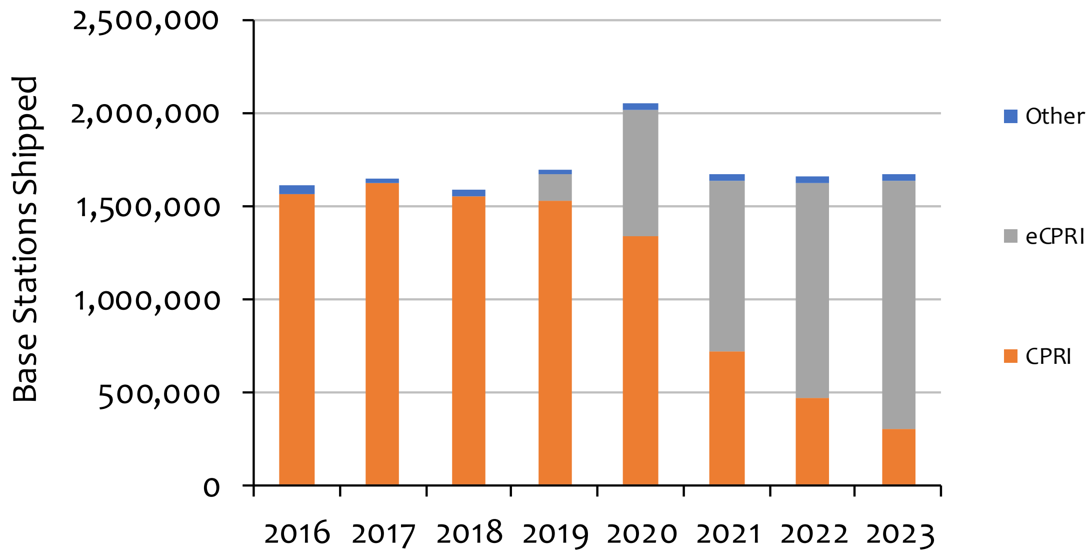
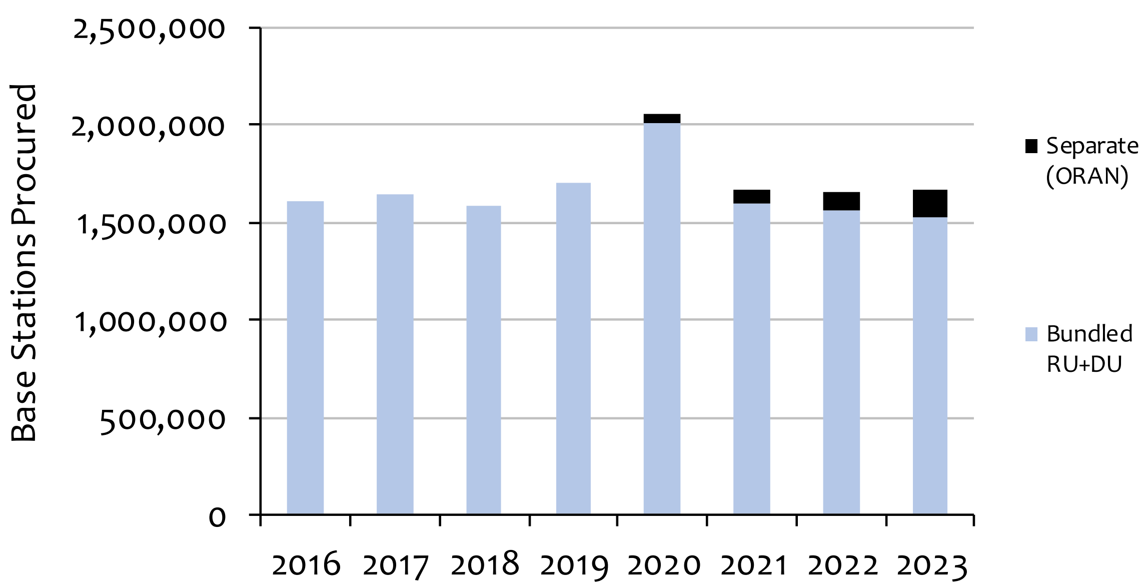


Chart 3: Global Base Station Shipments, by traffic density level, 2016-2023



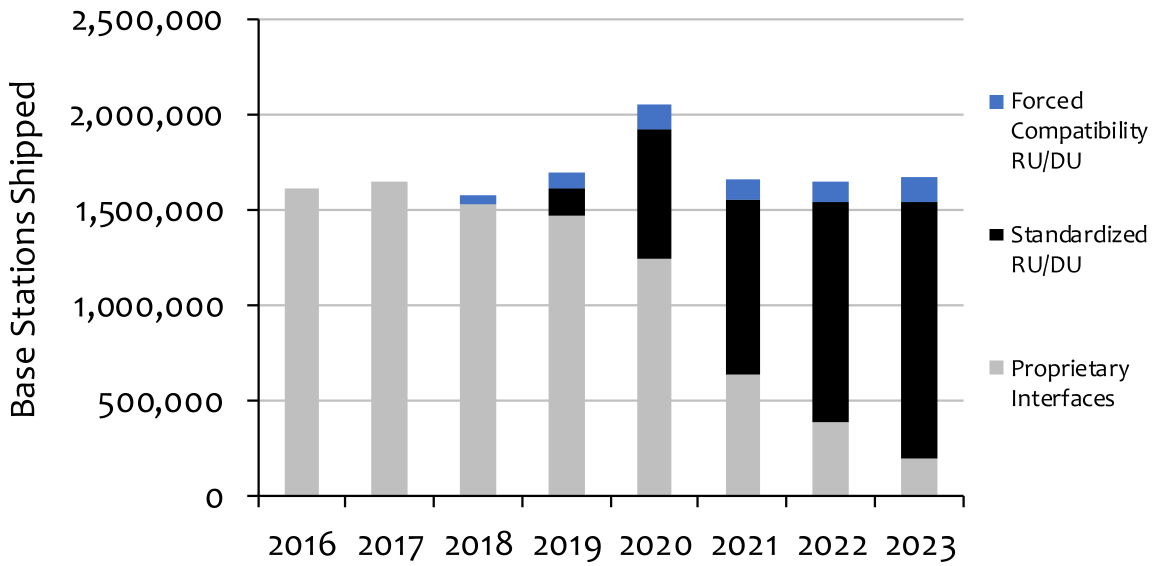
Source: Mobile Experts

Chart 4: Global Base Station Shipments, using CPRI and eCPRI, 2016-2023



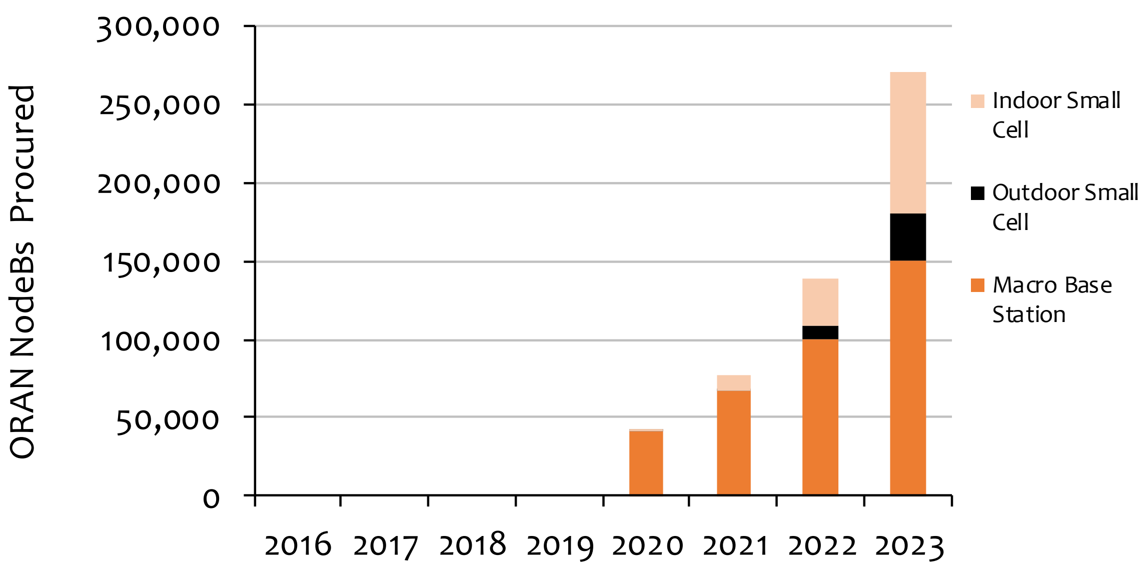
Source: Mobile Experts

Chart 5: Global Base Station Procurement, Separate vs. Bundled RU-DU, 2016-2023



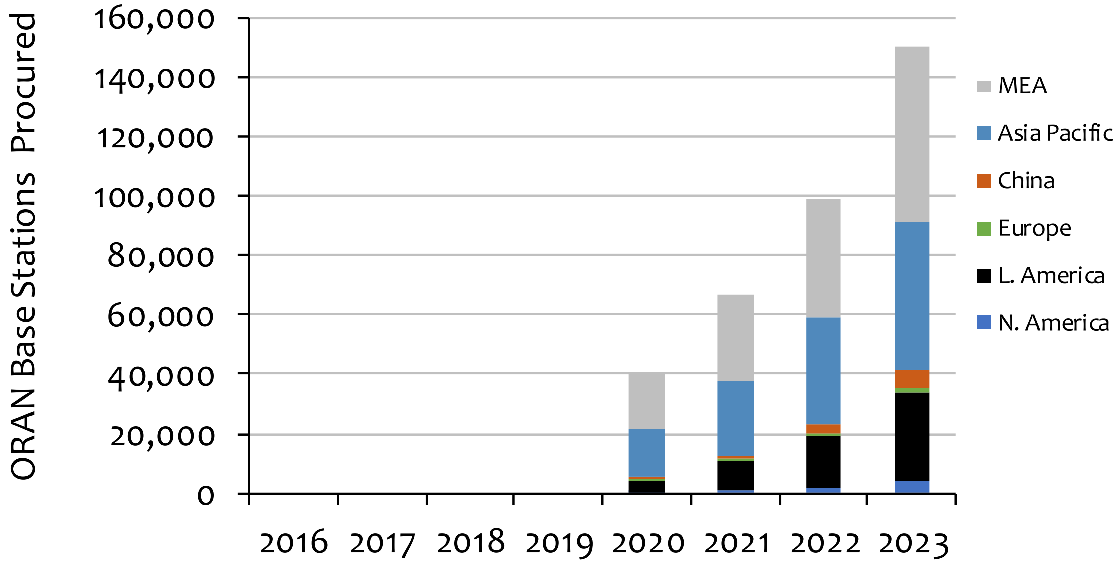
Source: Mobile Experts

Chart 6: Global Base Station Shipments, by RU-DU Interface, 2016-2023



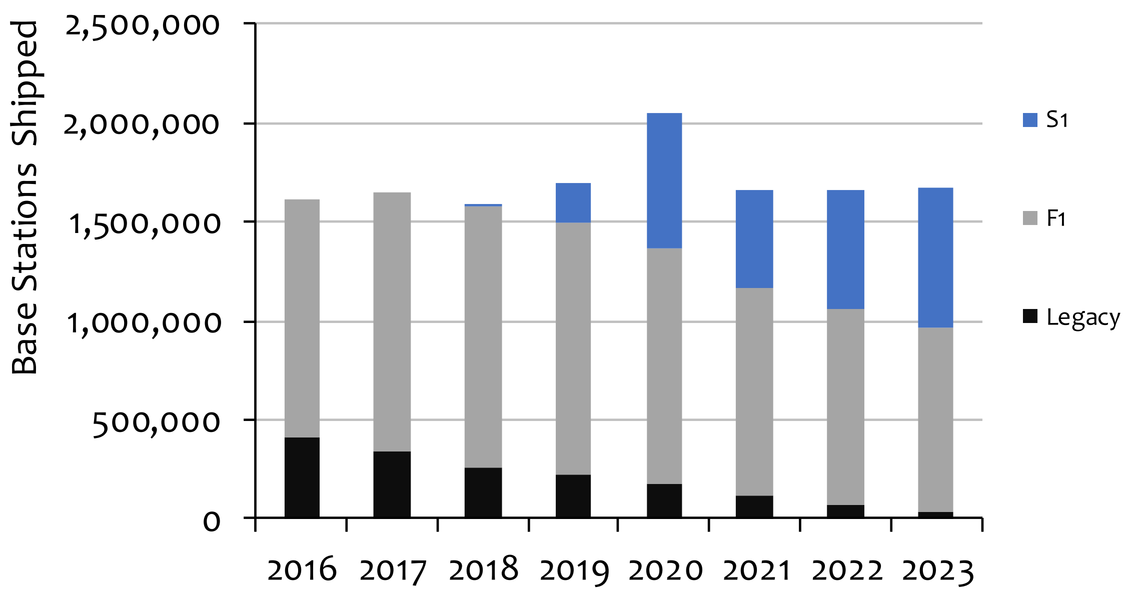
Source: Mobile Experts

Chart 7: ORAN nodeB Units Procured, Small Cell and Macro, 2016-2023



Source: Mobile Experts

Chart 8: Global Base Station Procurements, by Region, 2016-2023



Source: Mobile Experts

Chart 9: Global Base Station Shipments, by DU-CU Interface (S1, F1), 2016-2023

KEY COMPANIES

Software Vendors

Altiostar

Amarisoft

ASOCS

Mavenir

Phluido

Hardware/RRH and System vendors

AceAxis

Airrays

Baicells

Benetel

Blue Danube

Cisco

Commscope

Datang

Dell

Ericsson

Fujitsu

HPE

Huawei

KMW

Lenovo

MTI

NEC

Nokia

Parallel Wireless

Samsung

Supermicro

Tecore Networks

ZTE

Key Semiconductor Suppliers

Broadcom

Cavium

HiSilicon

Intel

Xilinx

GLOSSARY

2G:	Second Generation Cellular
3G:	Third Generation Cellular
4G:	Fourth Generation Cellular
5G:	Fifth Generation Cellular
BBU:	Baseband Unit
CBRS:	Citizens Broadband Radio Service, a shared wireless broadband use of the 3550-3700 MHz (3.5GHz) band in the US
CLEC:	Competitive Local Exchange Carrier
CPE:	Customer Premise Equipment (e.g., cable modem, broadband gateway)
CPRI:	Common Public Radio Interface
CRAN:	Centralized RAN
CU:	Control Unit (high level processing for base station control)
DAS:	Distributed Antenna System
DU:	Digital Unit (non-real time baseband processing)
eCPRI:	Enhanced Common Public Radio Interface
F1:	Fronthaul Interface Designation by 3GPP
GHz:	Gigahertz
GTP:	Group Transport Protocol
I/Q:	In-phase and quadrature baseband signal
IDAS:	Indoor Distributed Antenna System
IF:	Intermediate Frequency
IP:	Internet Protocol (or Intellectual Property)
LAA:	License Assisted Access
LMR:	Land Mobile Radio
LTE:	Long Term Evolution

LWA:	LTE Wi-Fi Aggregation
MAC:	Media Access Control
MEC:	Mobile Edge Computing
MHz:	Megahertz
MIMO:	Multiple input, multiple output spatial multiplexing
O&M:	Operations & Maintenance
OBSAI:	Open Base Station Architecture Initiative
ORAN:	Open RAN (referring to Open RAN Alliance)
PDCP:	Packet Data Convergence Protocol
PHY:	Physical Layer
PIM:	Passive Intermodulation
RAN:	Radio Access Network
RF:	Radio Frequency
RLC:	Radio Link Control
ROI:	Return on Investment
RRC:	Radio Resource Control
RRH:	Remote Radio Head (old terminology used for LTE)
RU:	Radio Unit (new terminology used for 5G architectures)
S1:	Backhaul Interface Specification by 3GPP for LTE
SDAP:	Shared Device Access Protocol
TIP:	Telecom Infra Project (Facebook initiative)
UDP:	User Datagram Protocol
W:	Watts of power
Wi-Fi:	Wireless Fidelity (unlicensed wireless communications)
xRAN:	Designation for xRAN Forum

METHODOLOGY

This report is different than most Mobile Experts forecasts, in which we rely on modeling of mobile traffic to predict demand for base station capacity, and we track hardware shipments to create a precise forecast. In this case, we surveyed CTO-level experts at 27 leading operators and multiple high-level experts within three large RAN vendors. We interviewed other experts in beamsteering and system optimization for guidance as well.

For this report, we relied on direct input in our survey, including examples from current network deployment, to arrive at rough estimates for the cost savings of ORAN networks in 5G. We relied on input in our survey to create a rough estimate of the performance advantage inherent in proprietary networks and optimization through non-standard coordination of multiple network elements. While this approach is not as scientific as our normal methods, in this case we trust that the high level experience of our interviewees has given us the benefit of many years of experience.

We applied our assumptions about performance advantages for proprietary networks, and the cost savings of ORAN networks, to our normal Macro Base Station and Small Cell forecasts. Our estimates of adoption for ORAN are based on our conclusions about different adoption in distinct market segments, ranging from urban networks in developed markets to rural networks in third-world markets.